

## METHOD AND SYSTEM FOR COMPENSATING THERMALLY INDUCED MOTION OF PROBE CARDS

### BACKGROUND OF THE INVENTION

The present invention relates to probe cards having electrical contacts for testing integrated circuits, and more specifically for a system and method to compensate for thermally induced motion of such probe cards. Probe cards are used in testing a die, e.g. integrated circuit devices, typically on wafer boards. Such probe cards are used in connection with a device known as a tester (sometimes called a prober) wherein the probe card is electronically connected to the tester device, and in turn the probe card is also in electronic contact with the integrated circuit to be tested.

Typically the wafer to be tested is loaded into the tester securing it to a movable chuck. During the testing process, the chuck moves the wafer into electrical contract with the probe card. This contact occurs between a plurality of electrical contacts on the probe card, typically in the form of microsprings, and plurality of discrete connection pads (bond pads) on the dies. Several different types of electrical contacts are known and used on probe cards, including without limitation needle contacts, cobra-style contacts, spring contacts, and the like. In this manner, the semiconductor dies can be tested and exercised, prior to singulating the dies from the wafer.

For effective contact between the electrical contacts of the probe card and the bond pads of the dies, the distance between the probe card and the wafer should be carefully maintained. Typical spring contacts such as those disclosed in U.S. Patent Nos. 6,184,053 B1, 5,974,662 and 5,917,707, incorporated herein by reference, are approximately 0.040", or about one millimeter, in height. If the wafer is too far from the

probe card contact between the electrical contacts and the bond pads will be intermittent if at all.

While the desired distance between the probe card and wafer may be more easily achieved at the beginning of the testing procedure, the actual distance may change as the testing procedure proceeds, especially where the wafer temperature differs from the ambient temperature inside the tester. In many instances, the wafer being tested may be heated or cooled during the testing process. Insulating material such as platinum reflectors may be used to isolate the effects of the heating or cooling process to some extent, but it cannot eliminate them entirely. When a wafer of a temperature greater than that of the probe card is moved under the card, the card face nearest the wafer begins to change temperature. Probe cards are typically built of layers of different materials and are usually poor heat conductors in a direction normal to the face of the card. As a result of this a thermal gradient across the thickness of the probe card can appear rapidly. The probe card deflects from uneven heat expansion. As a result of this uneven expansion, the probe card begins to sag, decreasing the distance between the probe card and the wafer. The opposite phenomenon occurs when a wafer is cooler than the ambient temperature of the tester is placed near the probe card. As the face of the probe card nearest the wafer cools and contracts faster than the face farthest from the wafer, the probe card begins to bow away from the wafer disrupting electrical contact between the wafer and the probe card.

## SUMMARY OF THE INVENTION

The invention is set forth in the claims below, and the following is not in any way to limit, define or otherwise establish the scope of legal protection. In general terms, the present invention relates to a method and system from compensating for thermally or otherwise induced motion of probe cards during testing of integrated circuits. This may include optional features such as energy transmissive devices, bi-material deflecting elements, and/or radial expansion elements.

One object of the present invention is to provide an improved method and system for compensating thermally induced motion of probe cards.

Further objects, embodiments, forms, benefits, aspects, features and advantages of the present invention may be obtained from the present disclosure.

THE "EFFECT" OF THE INVENTION

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a probe card.

FIG. 2 is a cross-sectional view of a probe card engaged with a wafer.

FIG. 2A is a cross-sectional view of a thermally distorted probe card engaged with a wafer.

FIG. 2B is a cross-sectional view of a thermally distorted probe card engaged with a wafer.

FIG. 3 is a cross-sectional view of a probe card assembly.

FIG. 4 is an exploded, cross-sectional view of a probe card according to one example of the present invention.

FIG. 4A is a cross-sectional view of the probe card of FIG. 4.

FIG. 4B is a top plan view of another example of a probe card according to the present invention.

FIG. 5 is an exploded, cross-sectional view of a probe card according to another example of the present invention.

FIG. 5A is a cross-sectional view of the probe card of FIG. 5.

FIG. 6 is an exploded, cross-sectional view of a probe card according to another example of the present invention.

FIG. 6A is a cross-sectional view of the probe card of FIG. 6.

FIG. 6B is a bottom plan view of the probe card of FIG. 6.

FIG. 7 is an exploded, cross-sectional view of a probe card according to another example of the present invention.

FIG. 7A is a cross-sectional view of the probe card of FIG. 7.

FIG. 8 is a cross-sectional view of a probe card according to yet another example of the present invention.

FIG. 9 is an exploded, cross-sectional view of a probe card according to another example of the present invention.

FIG. 9A is a cross-sectional view of the probe card of FIG. 9.

FIG. 10 is a flowchart depicting one example of a control program according to the present invention.

FIG. 10 is a flowchart depicting one example of a control program according to the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, and alterations and modifications in the illustrated device and method and further applications of the principles of the invention as illustrated therein, are herein contemplated as would normally occur to one skilled in the art to which the invention relates.

FIG. 1 shows a typical example of a probe card 110 and wafer 140 loaded into a tester. In this and the other accompanying views certain elements of certain components are shown exaggerated, for illustrative clarity. Additional components which may be mounted to the probe card, such as active and passive electronic components, connectors, and the like, are omitted for clarity. The present invention may be practiced with variations of the basic probe card design examples shown, such as probe cards incorporating interposers as shown in U.S. Patent No. 5,974,662, which is hereby incorporated by reference. No limitation of the scope of the invention is intended by the omission of these elements.

The probe card 110 is supported by the head plate 120 when mounted in the tester parallel to the die on a wafer 140, and most typically positioned directly above it. The probe card 110 is typically round, having a diameter on the order of 12 inches, although other sizes and shapes are also contemplated. The probe card 110 is generally a conventional circuit board substrate having a plurality (two of many shown) of electrical contacts 130 disposed on the wafer side 114 thereof. The electrical contacts are known in

the industry and hereinafter referred to as "probes" or "probe elements". A preferred type of probe element is spring contacts, examples of which are disclosed in U.S. Patent Nos. 6,184,053 B1; 5,974,662; and 5,917,707 which are hereby incorporated by reference. However, many other contacts are known in the industry (e.g., needle contacts and cobra-style contacts) and any such contact may be included in any embodiment of the probe cards of the present invention. Typically, the probe card is connected to the testing machine by other electrical contacts (not shown).

As is known, a semiconductor wafer 140 includes a plurality of die sites (not shown) formed by photolithography, deposition, diffusion, and the like, on its front (upper, as viewed) surface. Each die site typically has a plurality (two of many shown) of bond pads 145, which may be disposed at any location and in any pattern on the surface of the die site. Semiconductor wafers typically have a diameter of at least 6 inches, but the use of the present invention to test wafers of other sizes and shapes is also contemplated.

Once the wafer 140 is mounted in the testing device, wafer chuck 150 including table actuator 155 lift the integrated wafer 140 vertically in the Z-axis direction (see FIG. 2) to allow electronic contact between probes 130 and a corresponding pad (such as pads 145) of the wafer 140. The lifting mechanism may utilize a scissors mechanism, telescoping action, lever action, thread action, cam action or other lifting mechanisms. Such lifting mechanism, as with the other movements in the other embodiments, may be actuated by a variety of mechanisms such as pneumatics, stepper motors, servo motors or other electrical motors or otherwise and are typically robotically controlled. Such lifting mechanism may also allow for movement in the X and Y directions, tilt, and rotation.

Once the wafer 140 is moved into electrical contact with the probe card 110 (as shown in FIG. 2), the testing procedure may proceed.

FIG. 2 illustrates a wafer 140 in electrical contact with a probe card 110. The pressure contact of the probe elements 130 with the bond pads 145 provide this contact. For this contact to be produced, the wafer 140 is urged to an effective distance Z (vertical as shown) from the probe card. Typically, the height of the probes 130 used in the probe card is approximately 0.040", or about one millimeter, although probe card contacts of other heights are also contemplated by the present invention. As the probes 130 are generally somewhat flexible, the effective distance Z between the probe card 110 and the wafer 140 may differ from the height of the probes 130 being used. Of course the present invention naturally may be modified in accordance with the particular height or type of a particular probe card's electrical contacts.

FIGS. 2A and 2B illustrate the thermally induced motion of probe cards the present invention is directed towards. As shown in FIG. 2A, a wafer 140 having a temperature greater than the ambient temperature of the tester is engaged with the probe card 110. The card face nearest the wafer 114 begins to change temperature. As probe card assemblies are typically poor conductors of heat in a direction normal to the face of the card, a thermal gradient rapidly develops across the thickness of the probe card. The probe card behaves as a bimetallic element as the face nearest the wafer 114 warms and therefore expands more quickly than the face farthest from the wafer 112. As a result of this uneven expansion the probe card begins to sag. This movement decreases the actual distance Z' between the probe card 110 and the wafer 140 to something less than the optimal effective distance. Decreasing the distance between the probe card 110 and the



wafer 140 may result in movement of the probes 130 leading to overengagement of the probes 130 from the bond pads 145 and possibly deformation or even breaking the probe elements 130 or the semiconductor device being tested.

The opposite phenomenon occurs when a wafer 140 significantly cooler than the ambient temperature of the tester is placed near the probe card 130. As the face of the probe card nearest the wafer 114 cools it begins to contract faster than the face farthest from the wafer 112. As a result of this uneven cooling, the probe card 110 begins to bow away from the wafer creating an actual distance  $Z'$  between the wafer 140 and the probe card 110 greater than the optimal effective distance. If great enough this bow may disrupt electrical contact between the wafer 140 and the probe card 110 by disengaging some of the probes 130 from their corresponding bond pads 145.

As seen in FIG. 3, one solution to the problem of thermally induced or other motion of probe cards known in the art is the addition of stiffening elements 360, 365 to the probe card 110. Typically circular and made of metal, both wafer side stiffeners 360 and tester side stiffeners 365 are commonly employed. These stiffeners may be affixed in any suitable manner, such as with screws (not shown) extending through corresponding holes (not shown) through the probe card 110, thereby capturing the probe card 110 securely between the wafer side stiffener 360 and tester side stiffener 365. The stiffeners may also be individually mounted directly to the probe card 110 such as with screws (not shown). The use of stiffeners, however, may also lead to thermally induced movement of the probe card. As the metal stiffeners conduct heat better than the probe card 110, a thermal gradient can appear causing the metal stiffener on one side of the

probe card 110 to expand more than the metal stiffener on the other side of the probe card 110.

FIG. 4 shows an exploded, cross-sectional view of one example of the present invention. Although certain elements have been exaggerated for clarity, the dashed lines in the figure properly indicate the alignment of the various components. This example is a probe card assembly incorporating at least one energy transmissive device 470, 475 to compensate for thermally induced motion of the probe card. At least one such energy transmissive element 470, 475 is disposed between the probe card 110 and the stiffening elements 360, 365. In an another example of the present invention, two such energy transmissive devices 470, 475 are utilized, preferably one adjacent to the tester side of the probe card 112 and one adjacent to the wafer side of the probe card 114. These energy transmissive devices 470, 475 may be embedded in the stiffeners 360, 365 as shown, but this is not necessary. In yet another example of the present invention, a plurality of energy transmissive elements 470A, 470B, 470C (FIG. 4B) are disposed between the probe card 110 and the stiffening elements 360, 365. Preferably this plurality of energy transmissive elements is arranged in a generally circular pattern. Also, the individual elements of the plurality of energy transmissive devices may be operably linked so they may be controlled together. The present invention also contemplates the use of a plurality of energy transmissive elements where the individual elements are generally triangular and arranged generally forming a circle. The individual elements may also be generally ring shaped and arranged generally as concentric rings as seen in FIG. 4B. The present invention also contemplates a combination of generally triangular and ring shaped individual energy transmissive elements.

Any suitable energy transmissive device may be utilized to practice this particular example of the present invention. For example, thermal elements such as thin film resistance control devices are particularly suited to the present invention. Thermal elements which allow for both heating and cooling such as devices which absorb or give off heat at the electrical junction of two different metals (i.e. a Peltier device) may also be used. Energy transmissive devices which do not rely on thermal energy are also contemplated by the present invention. Devices which generate a mechanical force when a voltage is applied (i.e. a piezoelectric device) may also be used.

Energy transmissive devices 470, 475 which are thermal control elements may be utilized to compensate for thermally induced motion of the probe card 110 in several ways. For example, the temperature control devices may be operated continually at the ambient temperature of the tester or at some other preselected temperature. This would tend to drive the probe card 110 to a uniform temperature regardless of the temperature of the wafer 140 and thereby prevent deformation of the probe card 110. Alternatively, the temperature control elements 470, 475 may incorporate a temperature sensing element (not shown). By sensing the temperature of the two sides 112, 114 of the probe card, the temperature control elements 470, 475 may be directed to apply or remove heat as required to compensate for any thermal gradient developing within the probe card 110. It is understood that the control methods described hereinabove while making reference to an example of the present invention incorporating two temperature control elements 470, 475 are equally applicable to alternate examples employing a single temperature control device or a plurality of control devices.

Energy transmissive devices 470, 475 according to the present invention may also be operated by monitoring conditions of the probe card 110 other than temperature. For example, a device such as a camera, laser, or other suitable means may be used to monitor the actual distance  $Z'$  (see FIG. 2A) between the probe card 110 and the wafer 140. When this distance differs from the optimal distance  $Z$  by a preselected amount, the energy transmissive devices 470, 475 are engaged to correct this deviation. A logic loop control as described in the discussion of FIG. 10 may also be used. The present invention also contemplates the use of energy transmissive devices 470, 475 similar to those shown to control the temperature of elements which hold or support the probe card 110 such as head plate 120 as seen in FIG. 1.

Referring to FIG. 5, this drawing shows an alternate example of the present invention utilizing a bi-material stiffening element 580 to compensate for thermally induced motion of the probe card 110. Although certain elements have been exaggerated for clarity, the dashed lines in the figure properly indicate the alignment of the various components. The materials used in the bi-material stiffening element preferably expand at different rates to the input of energy. For example, the upper material 582 may have a different coefficient of thermal expansion than the lower material 584 such that the two materials will react to temperature changes at different rates. Typically the layers of the bi-material stiffening element will be composed of two metals having different coefficients of thermal expansion although other materials such as ceramics and plastics may also be used. Preferably the bi-material stiffening element is located at or near the perimeter of the probe card, but other configurations are also contemplated. The materials and the thickness of the materials are chosen such that the bow created in the

bi-material stiffening element 580 counteracts the expected bow of the probe card 110 for a particular application. For example, if the wafer 140 (which is typically located below the probe card 110 as shown in FIG. 2) is to be heated to a temperature greater than the ambient temperature of the tester, the bi-material stiffening element 580 would be selected such that the upper material 582 would have a greater coefficient of thermal expansion than the lower material 584. This would cause the upper material 582 to expand more rapidly than the lower material 584 giving the bi-material stiffening element 580 an upward bow to counteract the expected bow of the probe card 110 (as shown in FIG. 2A). Although not shown in FIG. 5, the present invention also contemplates the use of bi-material stiffening elements in place of the tester side stiffening element 365 as well as the use of multiple bi-material stiffening elements in the place of a single bi-material stiffening element. Additionally, the bi-material stiffening elements of the present invention may be attached to the probe card 110 by means described hereinabove for the attachment of stiffening elements to probe cards or by any other suitable method. The present invention also contemplates the use of a bi-material stiffener such that the probe card 110 is disposed between the layers of the bi-material stiffener.

FIGS. 6 and 7 illustrate variations of another example according to the present invention. The dashed lines in the figures properly indicate the alignment of the various components although certain elements have been exaggerated for clarity. This particular example of the present invention incorporates a means for allowing radial movement of the probe card 110 relative to the wafer side stiffening element 360. This radial movement means is disposed between the probe card 110 and the wafer side stiffening element 360. Specifically shown are rolling members 690 (FIG. 6) and lubricating layer

792 (FIG. 7), although other means for allowing radial motion of the probe card 110 relative to the wafer side stiffener 360 are also contemplated. The rollers 690 may be ball bearings, cylindrical bearings, or any other suitable shape. The lubricating layer 792 may be a layer of graphite or other suitable material. Alternatively, the lubricating layer 792 may be a low-friction film composed of a material such as diamond or Teflon®, or any other suitable material. This lubricating layer may be applied to the surface of the probe card 110, the surface of the stiffening element 360, 365, or both.

Although a fastening means between the probe card 110 and the wafer side stiffening element 360 is omitted from the illustration, it is understood that any suitable fastening method may be used. The wafer side stiffening element 360 may be fastened to the tester side stiffening element 365 or alternatively directly to the probe card 110 as described hereinabove. Although known fastening methods such as bolts or screws will typically allow for sufficient radial movement between the probe card 110 and the wafer side stiffening element 360, the present invention also contemplates the use of a fastening means allowing for greater radial movement such as radially oriented slots, dovetails or tracks. As shown in FIG. 6B, the wafer side stiffening element 360 may be fastened to the probe card 110 by bolts 692 which pass through slots 694 in the wafer side stiffening element 360. These bolts 692 may be fastened directly to the probe card 110 or may alternatively pass through holes (not shown) in the probe card 110 and fasten to the tester side stiffening element (not shown).

The example of the present invention illustrated in FIGS. 6 and 7 compensates for thermally induced motion of a probe card in the following manner. In the case of a probe card 110 exposed to a wafer 140 at a higher temperature than the ambient temperature of

the tester, a temperature gradient begins to develop across the probe card 110. The wafer side of the probe card 114 begins to expand more rapidly than the tester side 112 of the probe card. As the wafer side of the probe card 114 begins to expand, the rollers 690 allow for radial motion of the probe card 110 relative to the wafer side stiffening element 360. Typically only a small amount of radial motion is necessary to prevent deformation of the probe card. In some cases, movement of 10 to 20 microns is sufficient, although the present invention also contemplates embodiments allowing for greater and lesser degrees of radial motion.

Yet another example of the present invention may be described by referring to FIG. 8. In this particular example of the present invention, the distance between the wafer 140 and the probe card 110 is corrected during the testing procedure to compensate for thermally induced motion of the probe card. As previously described, once the wafer 140 is secured in the tester to the wafer chuck 150 it is moved to the effective distance Z from the probe card 110 to allow for engagement of the probes 130 with the bond pads 145. As testing proceeds, a thermal gradient in the probe card 110 may be induced by proximity to a wafer 140 at a temperature significantly different from that of the tester leading to thermally induced motion of the probe card 110 as shown in FIGS. 2A and 2B. To compensate for this motion, the present invention also contemplates a system whereby the distance Z between the probe card 110 and the wafer 140 is monitored during the testing procedure. As thermally induced motion begins the actual distance between the probe card 110 and the wafer 140 may change, this alteration is detected and the wafer 140 is returned to the optimally effective distance Z. For example, if the probe card began to sag as shown in FIG. 2A, the decrease in the actual distance Z' between the

probe card 110 and the wafer 140 is detected and the table actuator 155 lowered to return the wafer 140 to the optimal effective distance  $Z$  from the probe card.

The actual distance between the probe card 110 and the wafer 140 may be monitored by any suitable means. Once such means includes monitoring the pressure exerted on the probe elements 130 by the bond pads 145. Changes in this pressure can be monitored and a signal relayed to the control system for the table actuator to order a corresponding corrective movement of the wafer 140. This is but one specific example of a means for monitoring the distance between the wafer 140 and the probe card 110. Other means for monitoring this distance such as the use of lasers, including proximity sensors, captive proximity sensors, or cameras are also contemplated by the present invention. Such sensors may be a part of the tester or alternatively may be incorporated in the probe card.

Preferably the actual distance  $Z'$  between the wafer 140 and the probe card 110 is monitored by a computer using a logic loop similar to that shown in FIG. 10. After the user inputs the desired distance  $Z$  between the wafer 140 and the probe card 110 to be maintained 10, indicates the maximum allowable deviation from this distance 20, and any other information specific to the particular testing procedure, the testing procedure begins. The computer begins by detecting the actual distance  $Z'$  between the wafer 140 and the probe card 110 at the step labeled 30 using a suitable detecting means as previously described. The computer then compares the actual distance  $Z'$  to the desired distance  $Z$  at the step labeled 40. If the absolute magnitude of the difference between  $Z$  and  $Z'$  is greater than the maximum allowable deviation as set at box 20, then the computer applies the appropriate corrective action 80 before returning to box 30 to begin



the loop again. If the absolute magnitude of the difference between Z and Z' is less than the maximum allowable deviation as set at box 20, then the computer returns to the beginning of the logic loop 30. The corrective action taken at box 80 will of course depend on which particular corrective device or combination of devices as previously described are used with a particular probe card. Preferably where more than one device according to the present invention is used in a single probe card, a single computer will control all such devices, although this is not necessary. Preferably the control computer is a part of the tester although alternatively it may be incorporated on the probe card.

Control of the actual distance between the probe card 110 and the wafer 140 as previously described also compensates for probe card deformation other than thermally induced deformation. As the probe elements 130 are generally located near the center of the probe card 110 as seen in FIG. 1, the engagement of the probe elements 130 with the bond pads 145 imparts an upward (as shown) force on the center of the probe card 110. This force may lead to a deformation of the probe card 110 characterized by a bow near the center of the card. The control system previously described may also correct for this type of probe card deformation by monitoring and correcting the actual distance between the probe card 110 and the wafer 140.

Probe cards need not be limited to a single device described herein to compensate for thermally induced motion according to the present invention. Indeed, the present invention contemplates the combination two or more of the devices previously described in a single probe card. The example shown in FIG. 9 employs a tester side energy transmissive device 470, a wafer side energy transmissive device 475, a lubricating layer 792 to allow for radial motion of the probe card 110, and a bi-material stiffening element

